Aquatic Angiosperms in Coastal Saline Lagoons of New South Wales. IV. Long-term Changes

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KING, R. J., & HODGSON, B. R. Aquatic angiosperms in coastal saline lagoons of New South Wales. IV. Long-term changes. *Proc. Linn. Soc. N.S.W.* 109 (1), 1986: 51-60.

The area occupied by aquatic angiosperms and the biomass of *Zostera capricorni* have been documented for southern Lake Macquarie and the Tuggerah Lakes from 1980 to 1985. The area of seagrasses in Lake Macquarie ranged from 4.81 to 6.75km^2, and the total biomass of *Zostera* from 543 to 1099 tonnes. Winter biomass was significantly greater than summer biomass. In the Tuggerah Lakes the area was 13.13-19.11km^2 and total biomass of *Zostera* 840-1888 tonnes. Differences between years were not significant because of the wide variation shown in both parameters. The data show no time-related trends or predictable changes. When vegetation survey is to function as baseline data this inherent variability in seagrass populations must be recognized.

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INTRODUCTION

The disturbance of seagrass beds by natural and artificial causes and the recognition of the potential of such disturbances on commercial and recreational fishing have led to the recent increased interest in the biology of these plants (McRoy and Helfferich, 1977; Phillips and McRoy, 1980; McComb *et al.*, 1981). In Australia where some 11.4% of the coastline consists of coastal lagoons (Cromwell, 1971, in Barnes, 1980), and with the increasing residential and industrial development in proximity to the coastal water ways, such studies have especial relevance. In investigations of seagrass communities on the New South Wales coast there are few detailed early studies. Hence baseline studies, in which data are collected and analysed in order to specify the present state of the community, are a prime requirement. Generally such studies anticipate some environmental changes. The so-called 'baseline data' are essential to monitoring since change can only be detected in relation to the unimpacted state. When the impact has to be inferred from temporal change alone the sampling and statistical analysis is suboptimal in that a control area defined *a priori* is lacking (Green, 1979). In cases where any future impact is potentially able to affect a wide area, or act over a long time, the sampling of baseline data is critical. The problem is always to obtain sufficient quantitative information that takes into account natural fluctuations so that later comparisons can be meaningful.

In the long term studies in the coastal saline lagoons of the New South Wales coast there have been detailed studies relating seagrass growth to specific environmental factors (e.g. Harris *et al.*, 1980; Higginson, 1965) and very broad distribution studies in which the results are essentially qualitative (e.g. Wood, 1959a; Evans and Gibbs, 1981; West *et al.*, 1985). Studies of the former type at least allow some predictions to be made on the basis of environmental tolerances: from studies in the latter category change can usually only be confirmed when the seagrass is no longer present.

This paper provides data on areas of seagrass coverage and biomass of *Zostera capricorni* in two seagrass-dominated coastal lagoons on the central coast of New South

Wales (Lake Macquarie and Tuggerah Lakes). Long-term vegetation changes are discussed.

Study Area

The two study sites, Lake Macquarie and the Tuggerah Lakes, are on the central New South Wales coast and their aquatic vegetation is described in King (1986a,b) and King and Holland (1986). Both lake systems support commercial fishing and prawning, but are in areas with rapid urbanization and increasing recreational use. Proximity to major population centres and to coal deposits have made the lakes suitable sites for steam-generating power stations: Wangi (330MW), Vales Point (2195MW), and Eraring (2640MW) power stations on Lake Macquarie, and Munmorah power station (1400MW) on the Tuggerah Lakes. These power stations use steam-driven generating units, and the lake water is continuously drawn from an inlet channel to cool the condensors. The Electricity Commission of New South Wales commenced funding of long-term seagrass surveys in the early 1960s in the Tuggerah Lakes and in the early 1970s in Lake Macquarie. These early surveys evolved to the present quantitative surveys. The cooling-water discharges result in the production of artificial warm water effluents (5-9°C above ambient) in localized areas of the lakes. Given the potential impact of these cooling-water discharges as well as changes such as the increasing turbidity and levels of phosphorus in Lake Macquarie (State Pollution Control Commission, 1983), and comparable environmental changes in the Tuggerah Lakes, there was a perceived need for quantitative data on the seagrass communities.

Methods

Since winter 1980 the aquatic vegetation in the southern half of Lake Macquarie and in the Tuggerah Lakes has been mapped quantitatively on a regular basis. All areas were mapped in winter 1980 and 1981 and all areas have been mapped every summer since. In addition areas in Lake Macquarie, Myuna Bay and Wyee Bay, have been mapped every winter.

The vegetation was mapped and the areas of seagrass calculated using the techniques outlined in King (1986b) but in surveys prior to 1984 the distance from the shoreline to the seagrass boundary was measured using a marked tape rather than optical range-finders. The formulae relating percentage cover and biomass measures established in King and Barclay (1986) were used to convert the data from the maps into estimates of total biomass and living shoot biomass.

Results and Discussion

The results are given in a series of tables:

Table 1 Area occupied by seagrasses in southern Lake Macquarie (1980-1985).

Table 2 Biomass, total and living leaf, for seagrasses in southern Lake Macquarie (1980-1985).

Table 3 Area occupied by seagrasses in Tuggerah Lakes (1980-1985).

Table 4 Biomass, total and living leaf, for seagrasses in the Tuggerah Lakes (1980-1985).

A complete copy of the vegetation surveys (1980-1986) is available (King, 1986a).

LAKE MACQUARIE

The range of estimates for total area of seagrass in southern Lake Macquarie for winter 1980 – summer 1985 was 4.81km^2-6.75km^2 (Table 1) and differences between

TABLE 1

Areas (km²) of seagrass in southern Lake Macquarie in the years 1980-1985

Season & Year	W80	S81	W81	S82	W82	S83	W83	S84	W84	S85
LAKE MACQUARIE (Southern Lake) — areas listed separately below										
Zostera	5.28	5.15	6.66	3.85		4.02		4.65		5.81
Halophila	1.16	3.58	3.29	2.68		2.24		3.85		4.59
Ruppia	—	—	—	0.07		—		0.19		0.15
Posidonia	0.03	0.05	0.02	0.01		0.07		0.02		0.01
Total	5.49	5.99	6.75	4.92		4.81		5.00		6.65
MYUNA BAY (Eraring Power Stn outlet to Goonda Pt excluding Whiteheads Lagoon)										
Zostera	0.38	0.42	0.71	0.40	0.19	0.25	0.44	0.32	0.32	0.25
Halophila	0.16	0.37	0.35	0.24	0.08	0.27	0.37	0.27	0.30	0.29
Total	0.38	0.42	0.71	0.41	0.20	0.27	0.46	0.32	0.33	0.29
GOONDA POINT – FISHING STATION POINT										
Zostera	0.52	0.54	0.85	0.51		0.38		0.53		0.47
Halophila	0.02	0.09	—	—		0.19		0.32		0.26
Posidonia	0.01	0.02	0.01	0.01		0.01		0.02		0.01
Total	0.53	0.62	0.86	0.51		0.39		0.53		0.48
CRANGAN BAY ('Youth Camp' — Pt Wolstoncroft)										
Zostera	0.79	1.21	1.08	0.34		0.87		0.72		1.05
Halophila	—	0.31	0.33	—		0.09		0.19		0.31
Posidonia	0.02	0.03	0.01	+		0.06		+		+
Total	0.81	1.37	1.09	0.35		0.92		0.72		1.07
CHAIN VALLEY BAY (Vales Pt — Frying Pan Point)										
Zostera	1.30	1.12	1.53	1.05		0.87		1.02		1.16
Halophila	0.31	1.01	1.14	0.93		0.58		0.74		1.22
Ruppia	—	—	—	0.07		—		0.19		0.15
Total	1.43	1.33	1.58	1.33		1.04		1.05		1.25
WYEE BAY including MANNERING BAY (Vales Pt — Wyee Pt)										
Zostera	0.05	0.05	0.07	0.05	0.01[1]	0.09	0.16	0.21	0.20	0.27
Halophila	0.09	0.38	0.09	0.45	0.25[1]	0.43	0.82	0.53	0.83	0.83
Total	0.10	0.40	0.09	0.60	0.25[1]	0.48	0.84	0.53	0.86	0.83
WYEE POINT – BLUFF POINT										
Zostera	0.38	0.38	0.36	0.23		0.27		0.42		0.61
Halophila	0.23	0.40	0.35	0.36		0.17		0.32		0.60
Total	0.38	0.40	0.36	0.36		0.41		0.47		0.74
BONNELLS BAY (Shingle Splitters Pt — Rocky Pt)										
Zostera	1.86	1.43	2.06	1.27		1.29		1.43		2.00
Halophila	0.35	1.02	1.03	0.70		1.09		1.43		1.08
Total	1.86	1.45	2.06	1.36		1.30		1.43		2.00

1 Data for Mannering Bay only

values for different years and different seasons were not significant. Even within specific areas of the lake differences in the area occupied by seagrass were not significant. In Table 5 the data for seagrass areas are summarized along with comparative figures for 1953. The values for 1953 were measured by planimetry using an original map from the CSIRO 1953 survey. The error in measuring such small areas is great (approx. 10%) but based on the values presented there appears to have been an overall reduction in seagrass beds of about one third. This reduction is apparent in all areas of the lake. Part of this loss may be attributable to sedimentation though the estimate for loss of lake area due to this is only one to two hectares per year (SPCC, 1983). Secchi disc data indicate that lake turbidity has increased, and since the lower limit of seagrasses is thought to be limited by light this would also reduce the area of seagrass.

TABLE 2

Biomass (tonnes) of Zostera capricorni *in southern Lake Macquarie, Winter 1980 — Summer 1985. Winter surveys from 1982 onwards have included only Myuna and Wyee Bays. Maps of individual areas are given in King (1986)*

LAKE MACQUARIE	W80	S81	W81	S82	W82	S83	W83	S84	W84	S85
Total biomass										
Myuna Bay	87	34	231	47	55	43	115	72	69	26
Goonda-Fishing Stn Pt	117	51	264	75	—	65	—	64	—	52
Crangan Bay	188	115	296	52	—	176	—	132	—	227
Chain Valley Bay	340	166	299	153	—	142	—	229	—	171
Wyee Bay	13	1	2	1	<1	1	14	3	18	4
Wyee Pt-Bluff Pt	62	40	115	29	—	74	—	112	—	72
Bonnells Bay	292	136	548	174	—	201	—	427	—	289
TOTAL	1099	543	1755	531		702		1039		841
Above-ground biomass										
Myuna Bay	9	8	39	10	9	10	17	18	7	6
Goonda-Fishing Stn Pt	13	11	41	17	—	15	—	14	—	11
Crangan Bay	25	24	40	12	—	42	—	31	—	55
Chain Valley Bay	38	38	29	35	—	34	—	56	—	39
Wyee Bay	2	1	1	<1	<1	1	3	2	3	4
Wyee Pt-Bluff Pt	5	9	17	6	—	19	—	28	—	16
Bonnells Bay	24	29	74	39	—	46	—	107	—	67
TOTAL	116	120	241	120		167		256		198

There are no data with which to compare the values for areas occupied by individual seagrass species (Table 2) nor the values for *Zostera capricorni* biomass.

While the area occupied by seagrasses remained relatively constant the biomass changed considerably. Part of this is probably due to the marked seasonal change in the biomass of *Zostera*. In winter the ratio of above-ground biomass to total biomass was about 1:8 and in summer it was about 1:4. If the number of living leaves on the plants varies and is influenced by non-seasonal factors such as King and Holland (1986) suggested then the biomass estimates will be affected accordingly. Another factor influencing the changes between years is the relative contribution of other seagrass species to the area occupied.

TUGGERAH LAKES

In Tuggerah Lakes the range of values for the area occupied by seagrasses is $13.13km^2$ to $19.11km^2$ and again there are no trends in the data (Table 3). A comparison of the percentage of the total area of the lakes occupied by each of the three seagrass species over the period 1980-1985 and 1963-1966 (Higginson, 1968) is given in Table 6. This indicates a marked reduction in the area occupied by *Zostera capricorni*.

The area occupied by *Halophila ovalis* appears to have increased dramatically but in Higginson's surveys *Halophila* would have been recorded only when it grew in single species stands. When *Halophila* occurs in mixed communities it is almost always the other species which give the beds their overall physiognomy. In the period 1980-1985 *Ruppia megacarpa* had more than trebled in the area occupied, from $2.52km^2$ to $8.24km^2$. In the period during which Higginson observed the distribution of weeds in the

TABLE 3

Areas (km^2) of seagrass in Tuggerah Lakes in the years 1980-1985

Season & Year	W80	S81	W81	S82	S83	S84	S85
TUGGERAH LAKES — (Total)							
Zostera	10.92	8.66	15.96	12.85	16.69	14.61	12.26
Halophila	4.10	9.14	10.98	9.71	13.36	7.51	10.40
Ruppia	2.52	1.76	3.13	2.20	2.73	5.01	8.24
Total	14.34	13.13	17.60	14.19	18.64	16.28	19.11
TUGGERAH LAKE							
Zostera	7.31	5.60	11.05	8.93	13.12	10.27	9.58
Halophila	0.67	6.05	7.16	4.53	8.15	3.77	6.43
Ruppia	2.50	1.76	3.12	1.71	2.73	3.75	5.48
Total	9.93	9.76	12.06	9.04	13.12	11.43	12.69
BUDGEWOI LAKE							
Zostera	2.86	2.17	3.61	2.12	2.75	3.21	1.19
	(1.91)*	(1.24)	(2.01)	(1.06)	(0.98)	(2.12)	(0.58)
Halophila	2.55	2.19	2.20	2.94	3.96	2.62	2.49
	(1.83)	(1.27)	(1.89)	(1.76)	(2.19)	(1.93)	(1.34)
Ruppia	0.02	—	0.01	0.33	—	0.98	2.22
	(—)	(—)	(—)	(0.06)	(—)	(0.44)	(1.71)
Total	3.05	2.28	3.82	3.00	4.19	3.43	4.03
MUNMORAH LAKE							
Zostera	0.75	0.89	1.30	1.80	0.82	1.13	1.49
Halophila	0.88	0.90	1.61	2.24	1.25	1.12	1.48
Ruppia	—	—	—	0.16	—	0.28	0.54
Total	1.36	1.09	1.72	2.25	1.33	1.42	2.39

*Data in brackets are for the Budgewoi Flats.

Tuggerah Lakes (1963-1966) the percentage of the area which was occupied by *Ruppia* fell from 13.3% to zero. Such wild fluctuations in the populations of *Ruppia* have also been observed in Smiths Lake (Myall Lakes system) but the factors involved have not yet been recognized. From the data available on the total area occupied by seagrass it does not appear that the increase in the area occupied by *Ruppia* is completely at the expense of *Zostera* and *Halophila* (Fig. 2).

The only biomass figures available for Tuggerah Lakes are not directly comparable with the data in Table 4 since they are for all seagrasses. The values were a maximum, in 1964, of 21,000 tons, and a minimum, in 1967, of 2,300 tons. These values seem to have been arrived at by multiplying the dry weight values obtained for quadrat samples by the area of the lake occupied by *Zostera* and the upper limit is considerably more than could be anticipated (see King and Holland, 1986). The range is far wider than that recorded here, 840-1888 tonnes (Table 4). In Tuggerah Lakes the ratio of above-ground biomass to total biomass was about 3 at all seasons.

The justification for many environmental surveys in the marine and coastal zones is that they are base-line studies against which man-induced change can be measured. Gray (1976) has noted that many such surveys are inadequate to the task of monitoring subtle, naturally-occurring changes and that they generally neglect the majority of the living constituents in the ecosystem.

Examination of the published data on the seagrasses of the Central Coast lakes reveals three problems:

TABLE 4

Biomass (tonnes) of Zostera capricorni *in Tuggerah Lakes, Winter 1980-Summer 1985*

TUGGERAH LAKES	W80	S81	W81	S82	S83	S84	S85
Total biomass							
Tuggerah Lake	627	747	1514	945	1159	1258	1052
Budgewoi Lake	169	127	236	219	242	456	89
Munmorah Lake	44	45	138	157	67	88	114
TOTAL	840	919	1888	1321	1468	1802	1255
Above-ground biomass (living leaf)							
Tuggerah Lake	213	291	642	369	443	499	376
Budgewoi Lake	50	47	78	86	92	183	34
Munmorah Lake	12	16	53	60	25	33	43
TOTAL	275	354	773	515	560	715	453

TABLE 5

Areas of seagrass in Lake Macquarie (km^2) 1980-1985, compared with values measured from CSIRO maps, 1953 (R. J. MacIntyre, pers. comm.)

	Year of Survey	
	1980-85	1953
Lake Macquarie (all areas)	14.17*	21.34
Myuna Bay (Eraring Power Stn outlet to Goonda Pt excluding Whiteheads Lagoon)	0.20-0.71	0.78
Goonda Pt to Fishing Station Point	0.39-0.86	1.22
Northern lake (Fishing Station Point to Cardiff Point)	1.58*	3.22
Central eastern part of lake (Cardiff Point — 'Youth Camp')	5.10*	7.28
Crangan Bay ('Youth Camp' — Pt Wolstoncroft)	0.35-1.37	0.65
Chain Valley Bay (Frying Pan Point to Vales Point)	1.04-1.58	2.05
Wyee Bay including Mannering Bay (Vales Point to Wyee Point)	0.09-0.86	1.56
Wyee Point to Bluff Point	0.36-0.74	1.53
Bonnells Bay (Shingle Splitters Point to Rocky Point)	1.30-2.06	2.49

* value for 1985 summer only.

1. All surveys are a compromise between the area covered and the detail of information collected. Earlier surveys of both Lake Macquarie and Tuggerah Lakes showed presence and absence of the seagrass species and these were presented as maps for each of the lake systems, but at very small scale [(1:*c*.180,000 for Lake Macquarie (Wood, 1959a) and 1:*c*.190,000 for Tuggerah Lakes (Higginson, 1965)]. These surveys also included global figures for the area covered by seagrass, and Higginson (1971) presented biomass figures for all aquatic angiosperms in the entire Tuggerah Lakes system.

   From these sorts of data absolute conclusions can only be drawn when seagrass has entirely disappeared from an area which it formerly colonized. The scale of the published maps makes it impossible to draw conclusions about specific areas of the lakes which may have been 'impacted'.
2. The seagrass beds in the Central Coast lakes occur in an area undergoing rapid urbanization. As well as thermal effects associated with power stations there are environmental changes due to other factors, especially increasing sedimentation, toxic metal pollution, and increased nutrient levels from fertilizers and sewage (Higginson, 1971; Interdept. Comm., 1979). In the absence of information on species inter-

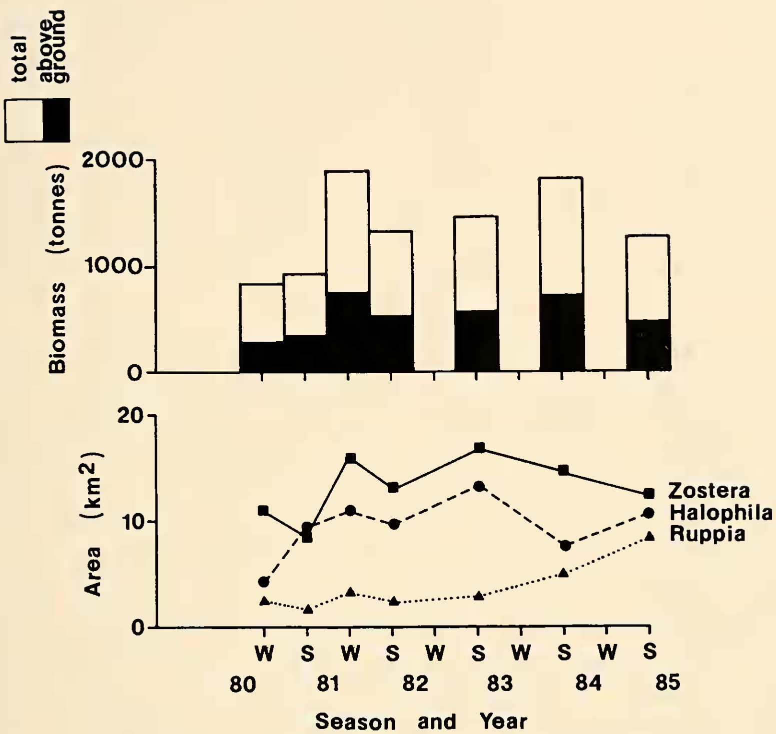

Fig. 1. Areas (km^2) occupied by the three aquatic angiosperms: *Zostera capricorni*; *Halophila ovalis*; and *Ruppia megacarpa* in Tuggerah Lakes, and biomass for *Zostera*.

actions, between even the common species and the environment, it is not possible to attribute community change to any one of the concomitant environmental perturbations.

Optimal impact study design requires the selection of a control area, or spatial control (Green, 1979). Whether such a control area, which is uninfluenced by the 'impact' under study but in other ways is similar to the area under investigation, can be designated *a priori* is a matter which can be generally argued (Gray, 1976). On the basis of the data available for the present study it seems unlikely.

3. In the absence of an adequate control area impact must be inferred from temporal change alone. In order to interpret such changes long-term systematic sampling and recording is necessary, and it must be assumed that observed changes would not have occurred if the area had not been environmentally altered.

With vegetation which changes as rapidly, as unpredictably and by such a magnitude as the present data indicate such an assumption may be unwarranted. Changes would need to be extensive and long lasting before firm conclusions could be drawn.

Wood (1959b) was able to state — 'the taxonomy of the Australian sea-grasses has been dealt with by several workers, but no ecological studies have been made'. In the same year he published his preliminary study on the plant communities of Lake

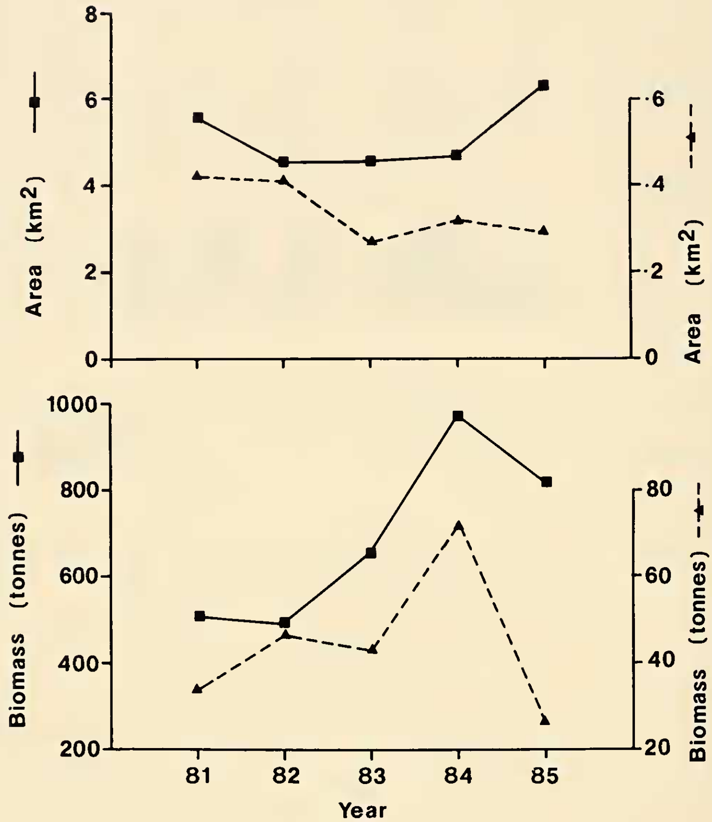

Fig. 2. Area (km^2) and total biomass occupied by aquatic angiosperms in Myuna Bay compared wtih value for the total area of southern Lake Macquarie.

Macquarie (Wood, 1959a) and their significance, *and* in an enviable display of honesty stated — 'only generalities are possible regarding the requirements of the sea-grasses'. Since that time seagrass ecology has received a great deal of attention but the unexplained variability in species composition, distribution, and biomass of seagrass beds in the Central Coast lakes still leaves us in a position where we could state very little without qualification. There is certainly some evidence from Australian studies and elsewhere that seagrass beds undergo drastic changes even under natural (non-impacted) conditions (Larkum and West, 1983). One specific area which remains unstudied is the means by which populations cope with environmental change. What is the importance of acclimatization in environmental response, and/or ecotypic variation?

In North America Phillips (*in* Phillips and McRoy, 1980: 29-40) has reported the use of leaf width to indicate environmental stress: narrow leaves indicate stress, broader leaves more optimum conditions. There have been no such morphometric studies in eastern Australia, though Larkum *et al.* (1984) recorded leaf widths at various sites for *Zostera capricorni* in Botany Bay.

TABLE 6

Area of seagrass in Tuggerah Lakes expressed as a percentage of the total lake area, compared with values given by Higginson (1968). Note that the values given in Higginson are for the community dominants only whereas data in the present study record all species in mixed beds

	Higginson (1968)			Present study
	May '63	Aug '65	Aug '66	Period: Winter '80/Summer '85
Zostera capricorni	27.8	27.5	27.7	11.2-21.7
Halophila ovalis	0.8	0.5	0.6	5.3-17.4
Ruppia megacarpa	13.3	3.3	0.0	2.3-10.7
Total seagrass	41.9	31.2	28.2	17.1-25.0

CONCLUSIONS

Long-term studies in southern Lake Macquarie and the Tuggerah Lakes, of both the area covered by seagrasses and the biomass of the major species, *Zostera capricorni*, showed that marked fluctuations are inherent in the nature of the communities. Over the period 1980-1985 these fluctuations did not appear to follow any regular or even predictable pattern. Data such as those presented by Higginson (1965, 1968), King (1986b) and King and Holland (1986) cannot be directly used as baseline data since they present the results of only single surveys and therefore fail to take into account this variation in time. Long-term changes can be recognized by comparing earlier data with those here but most earlier information is less detailed. Relative changes in abundance and distribution of seagrass can be detected by following long-term change, in which case the extent of change must be greater than the magnitude of the changes due to inherent variability, or by comparison against a control area. The selection of a control area is difficult since apart from the habitat both the species and their distribution must be similar. It is doubtful whether such control areas exist let alone can be recognized. In the case of a specific impact such as the discharge of cooling water effluent into Myuna Bay since early 1982 it may be valid to use the combined data for all other sites in southern Lake Macquarie as a control. When this was done there were no significant differences between Myuna Bay and the 'control' area for either area of seagrass or biomass of *Zostera capricorni* (Fig. 2) but such areas require monitoring to see if the trends which are apparent from the graph are continued.

Even large changes in seagrass distribution must be interpreted with caution. The disappearance of *Ruppia megacarpa* from large areas of the Tuggerah Lakes in 1965 could have been interpreted as resulting from drought conditions which existed at that time and its reappearance in quantity since 1984 may be due to subsequent environmental change. Such marked fluctuations are not a peculiarity of this lake system. Personal observations in Smiths Lake (Myall Lake system) show that *Ruppia* populations there exhibit changes of a similar magnitude.

On the basis of what few data are available from earlier studies it is apparent that the area of seagrass recorded in earlier studies of both Lake Macquarie and Tuggerah Lakes has decreased. In both cases this may be attributed to increasing turbidity, but this has not been demonstrated.

ACKNOWLEDGEMENTS

The continued support of the Electricity Commission of New South Wales has allowed us to pursue this project for over 8 years. We are grateful to G. C. Coulter (Manager: Power Development Division) for his long-term support and his recognition of the value of such studies.

In preparing this review of the project we have drawn on the work of several honours and graduate students and to them we are indebted: J. B. Barclay; M. McD. Harris; V. M. Holland; K. Sweaney and L. G. Watson. We are also pleased to acknowledge the help of technical staff of the Electricity Commission, especially Bill Jefferson and Peter Smith, and from the Botany School, University of New South Wales: Dr P. Farrant, M. A. Alderton, S. Francis, and B. L. J. Kertesz. Special thanks are due to those technicians directly involved in field surveys: G. Allen, N. Jacobs, G. Jenkins, S. McOrrie, J. Merrin, J. Nixon, L. Poole-Warren, R. Schneider, J. T. van der Velde, and L. G. Watson. Dr R. J. MacIntyre kindly made available the copy of the vegetation survey of Lake Macquarie: CSIRO Aug. (1953).

During the course of this project we have discussed ideas with many colleagues but Dr P. Adam deserves our special thanks.

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